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A Predictive Geomagnetic Field Model for Epoch 1990.5

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ABSTRACT

A predictive model of the geomagnetic field for epoch 1990.5 has been developed. The model is based on the DGRF model for 1980.5 updated to 1990.5 by use of a secular variation model for 1980.0 developed at the Naval Oceanographic and Atmospheric Research Laboratory (NOARL). The NOARL secular variation model is based upon annual means of vector geomagnetic field components from 73 magnetic observatories for years 1976.5 through 1983.5. The predictive model is of degree and order 10.

The rms error of the predictive model is estimated to be 200 nT relative to an accurate degree 10 field model for epoch 1990.5. Peak errors relative to an accurate model are estimated to be 500 nT for vector field error magnitude and ±350, ±250, and ±500 nT for north, east, and vertical field components errors, respectively. If the DGRF model for 1980.5 were used without updating to represent the degree 10 field for 1990.5, estimated errors would be about four times as large.

Keywords: Geomagnetism; Test methods; Mathematical prediction/models.

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1. Introduction

The U.S. Navy is responsible within the Department of Defense for production of global geomagnetic field models. These models are used for navigation and related applications. The Naval Oceanographic Office (NAVOCEANO) accumulates necessary magnetic field measurement data and produces such models every 5 years. Because the geomagnetic field changes with time, a model of the time variation (secular variation) of the field is also produced for use in updating the field model in the period between production of field models.

The Naval Oceanographic and Atmospheric Research Laboratory (NOARL) is engaged in an ongoing basic research program aimed at increasing understanding of time variations of the geomagnetic field and determining the best methods for modeling and predicting the geomagnetic field. This research has not been completed; however, models of secular variation have been produced for each year from 1962.0 through 1983.0, using vector magnetic field data at 73 magnetic observatories as the data source.

An epoch 1990.5 geomagnetic field model will be produced by NAVOCEANO using magnetic field measurements from the recently launched (April, 1990) POGS satellite for part of the input data.

To aid in the production and evaluation of this model, NAVOCEANO requested that NOARL produce a predictive field model for 1990.5.

Section 2 of this technical note describes production of the predictive epoch 1990.5 field model from a standard 1980.5 field model (the DGRF model) updated to 1990.5 through use of the NOARL secular variation models. In section 3 the NOARL secular variation models are described. An error analysis for the predictive field model is given in section 4. Conclusions given in section 5 include suggestions on how the predictive field model might be improved.

2. Epoch 1990.5 Predictive Field Model

Gauss coefficients for the NOARL epoch 1990.5 predictive field model are shown in Table (1). This model is called NOARL90. The coefficients are for the Schmidt seminormalized spherical harmonic representation commonly used in geomagnetism. The NOARL90 model was produced by updating the DGRF model for 1980.5 by use of a NOARL secular variation model for 1980.0. Coefficients of the DGRF model are shown in Table (2). This DGRF model is called DGRF80 and is described by Langel (1988). The NOARL secular variation model is called NOARL80S and its coefficients are shown in Table (3). The DGRF80 model was updated to produce the predictive NOARL90 model by adding coefficients of the NOARL80S model multiplied by 10 years to corresponding coefficients of the DGRF80 model. Units

for the NOARL90 and DGRF80 models are nT while units for the NOARL80S model are nT/yr.

The NOARL80S secular variation model was produced by averaging NOARL secular variation models for years 1977.0 through 1983.0; that is, corresponding coefficients for these models were averaged. Since the NOARL secular variation models for the individual years 1977.0 through 1983.0 are in geomagnetic coordinates, it was necessary to transform coefficients from the geomagnetic coordinate system to the standard geocentric coordinate system aligned with Earth's rotation axis.

Another predictive 1990.5 field model was produced from the IGRF85 model and IGRF85S secular variation model by linear extrapolation. These IGRF models are described in the article by Langel (1988). The new predictive model produced at NOARL from the IGRF85 and IGRF85S models was called GSFC90. A difference model D90 was computed from NOARL90 and GSFC90 by subtracting corresponding coefficients of GSFC90 from those of NOARL90. Field components for D90 were computed on a grid 10 degrees by 10 degrees in latitude and longitude and the scalar field for D90 was then computed at the grid points from the square root of the sum of the squares of the field components. The scalar field for D90 is represented by the contour plot of Figure (1) as a function of geographical location; the contour plot was derived from the scalar field at the grid points. Maximum difference field magnitude is

about 480 nT and occurs in the South Pacific at a location far from the nearest magnetic observatory. Difference field D90 reflects errors in one or both of the predictive field models. It will be shown in section 4 that the large difference field in the South Pacific is probably due mostly to errors in the GSFC90 predictive model.

3. NOARL Secular Variation Model

A set of secular variation models has been produced by NOARL from annual means of magnetic observatory vector field measurements. The models were produced from first differences of annual means of field components at 73 observatories which had vector measurements for each of the years 1961.5 through 1983.5. A separate secular variation model was produced for each year 1962.0 through 1983.0. The models were of degree and order 9 for internal source terms and the gaussian coefficients were obtained for a geomagnetic coordinate system. External source terms were included in the models for zonal harmonics of degrees 1, 3, 5, 7.

The method of stochastic inversion was used to produce the models; this method is discussed by McLeod (1986). Use of this method requires an error covariance matrix for the first differences of the observatory field components and an a priori parameter covariance matrix. Both of these covariance matrices were taken to be diagonal, corresponding to an assumed statistical

independence for the different measurement errors and assumed isotropy and spatial stationarity for the random process representing the internal source geomagnetic field. Parameter variances for the internal source field were based on a function that was fit by McLeod (1985) to the 1975 secular variation spatial power spectrum derived from the GSFC(9/80) model described by Langel et al. (1982). The function fit to the 1975 secular variation spatial power spectrum was:

$$F(n) = 100(2n + 1)^3(c/a)^{2n} \qquad (nT/yr)^2 \qquad (1)$$

where n is degree of the spherical harmonic, c is core radius (3485 km), a is mean earth radius (6371.2 km), (c/a) = 0.547. This function F(n) represents the mean squared value of that portion of the field derivative represented by spherical harmonics of degree n, and was given by McLeod (1985). Since there are (2n + 1) spherical harmonic coefficients of degree n and the mean squared field associated with each coefficient is (n + 1) multiplied by the square of the coefficient, the a priori parameter variances used in the stochastic inversion were:

$$C(n) = 400(n + 1/2)^2(n + 1)^{-1}(0.547)^{2n} \qquad (nT/yr)^2 \qquad (2)$$

where C(n) is the a priori variance for any of the coefficients of degree n.

Locations of the 73 magnetic observatories used for the secular variation models are shown in Figure (2a). Table (4) lists estimated rms errors for each field component at each observatory. These error estimates are based on rms values of third differences of individual field components at individual observatories for the interval 1961.5-1983.5. The field components are in geomagnetic coordinates and a model external field was subtracted from observatory measurements before computing third differences. A more detailed discussion of the production of the NOARL secular variation models is given in a paper by McLeod (in preparation). The a priori variances used in the inversion for the external zonal coefficients of degrees 1, 3, 5, 7 were 178, 0.44, 0.11, 0.11, respectively in units of (nT/yr) .

Table (4) shows estimated rms errors in the model at various observatories in units of nT/yr and also expressed as a percentage of measurement error at the various observatories. Estimated model error was computed from the error covariance matrix and a priori parameter covariance matrix by the method discussed by McLeod (1986). Estimated model error was also computed on a grid of latitude and longitude. Estimated rms error of the model vector field is shown as a function of geographic location in the contour plot of Figure (2b).

It can be seen from the contour plot of Figure (2b) and the estimated errors of Table (4) that the model is most accurate in

regions where there is a high density of observatories, such as Europe. The model is most inaccurate in regions far from a magnetic observatory, such as the South Pacific. At isolated observatories, such as Honolulu or Hermanus, the model fits measurement data nearly the same, so the model error is nearly the same as measurement error, but in regions where there are many observatories model error is less than observatory measurement error because the model effectively averages measurements from several nearby observatories.

4. Error Analysis

Errors in the NOARL90 predictive field model are due to three causes: (a) errors in the DGRF80 model, (b) errors in the NOARL80S secular variation model, and (c) errors due to the fact that secular variation is not constant from 1980 to 1990 but is time varying. Errors due to errors in NOARL80S can be estimated conservatively from the contour plot shown in Figure (2b) by multiplying errors in nT/yr shown in that figure by the 10 year interval from 1980 to 1990. This estimate is conservative because errors shown in Figure (2b) are for a model based on first differences of annual means for a single pair of years while NOARL80S is the average of seven such models.

In order to estimate accuracy of the NOARL90 model, a similar model was computed for epoch 1980.5 and named NOARL80. This model

is an update of the DGRF70 field model computed with the aid of a secular variation model NOARL70S. This secular variation model was computed by averaging NOARL secular variation models for years 1967.0 through 1973.0. Thus expected rms errors for the NOARL80 model are the same as those for the NOARL90 model, provided the underlying random process is temporally stationary. (The term "expected rms errors" is used in the statistical sense.) Coefficients of the DGRF80 model were subtracted from corresponding coefficients of the NOARL80 model to form a difference model D80. If errors in the DGRF80 model are negligible in comparison with errors in the NOARL80 predictive model, then D80 represents the error for the NOARL80 model. Contour plots of the field derived from the difference model D80 are shown in Figures (3a), (3b), (3c), and (3d). These figures show the scalar field, north, east, and vertical components, respectively.

The contour plot of Figure (3a) shows no similarity to the contour plot of Figure (2b); thus, errors in the NOARL70S secular variation model are not the principal source of errors in the NOARL80 predictive field model. Since it is improbable that errors in the DGRF70 or DGRF80 models are large enough to produce the difference fields shown in Figure (3a), the difference field D80 must be due to changes in secular variation between 1970 and 1980. To verify that this is the case, coefficients of secular variation model NOARL70S were subtracted from corresponding coefficients of secular variation model NOARL80S to obtain change in secular

variation for this 10 year time period. Field components of the difference model are shown in contour plots of Figures (4a), (4b), (4c), and (4d). Contour plots of Figure (4) are very similar to contour plots of Figure (3). Numerical values for Figure (3) are about five times those for Figure (4), as would be expected if errors shown in Figure (3) are due to the change of secular variation shown in Figure (4).

Because NOARL90 and NOARL80 were produced by the same methods, most of the error in the NOARL90 predictive model is probably due to changes in secular variation during the time period 1980 through 1990, and estimated rms error in the field corresponding to the NOARL90 model is about the same as rms errors seen in Figure (3). Thus estimated rms error for the predictive model NOARL90 is 200 nT and peak errors for the field components are estimated to be ±350, ±250, ±500 nT for north, east, and vertical components, respectively. Estimated peak value of the vector error magnitude is 500 nT.

Because the error for the NOARL80 predictive model does not show a large peak in the South Pacific in the contour plot of Figure (3a), the peak in the South Pacific region seen in the contour plot of Figure (2b) is probably not due to errors in the NOARL90 model but instead the peak is probably due to errors in the GSFC90 model. Such errors would be expected if the degree and order for the IGRF85S model, used to update the IGRF85 model to 1990.5, were too

high for the density of observatories in the South Pacific region. Spherical harmonic models produced by the usual least squares fit are known to attain large error magnitudes in regions where the density of observatories is low if the degree and order of the model is too great. The method of stochastic inversion used to produce the NOARL secular variation models minimizes this type of error.

In order to see what rms errors would result if the DGRF80 model were used to represent the epoch 1990.5 field without using a secular variation model for updating the DGRF80 model, the coefficients of the DGRF70 model were subtracted from corresponding coefficients of the DGRF80 model. The scalar field of the difference model is represented in Figure (5) by a contour plot as a function of geographical location. It can be seen by comparing Figure (5) with Figure (3a) that errors are about four times as large as they are when a secular variation model is used for updating an earlier field model.

As previously noted, errors in the predictive field models NOARL90 and NOARL80 are mainly due to changes in secular variation in the 10 year period between the epoch of the predictive model and the epoch of the model being updated. Thus it was thought that these errors might be reduced if the secular variation model were first updated to the midpoint of the 10 year interval. A secular variation model NOARL75S was produced from NOARL70S by averaging

the NOARL secular variation models for 1967.0 through 1969.0 and 1971.0 through 1973.0, subtracting the first average from the second and dividing by 4 years to get the secular acceleration for 1970.0, multiplying the secular acceleration by 5.5 to get the change of secular variation from 1970.0 to 1975.5, and finally adding coefficients for the change of secular variation to corresponding coefficients of NOARL70S to get NOARL75S. The new secular variation model NOARL75S was used to update the DGRF70 model to 1980.5 in the same way that NOARL70S was previously used to obtain the predictive model NOARL80. The new predictive model was called NOARL80-2. The difference D80-2 between the predictive model NOARL80-2 and the DGRF80 model was found. The rms field corresponding to D80-2 was larger than the rms field corresponding to D80; therefore, this new method for constructing a predictive field model is apparently not as good as the method used to produce NOARL80 and NOARL90.

5. Conclusions

A predictive geomagnetic field model for epoch 1990.5 has been developed. This model is called NOARL90 and is of degree and order 10. Model NOARL90 is based on the DGRF80 model updated to 1990.5 through use of a secular variation model NOARL80S for epoch 1980.0. Estimated rms error for NOARL90 is 200 nT while peak errors are estimated to be approximately 500 nT in magnitude for the vector field and ±350, ±250, ±500 nT for the north, east, and vertical

field components, respectively. Errors are primarily due to changes in secular variation during the 10 years between the epoch of secular variation model NOARL80S and the epoch of predictive model NOARL90. Estimated errors would be about four times larger if DGRF80 were used without updating to represent the epoch 1990.5 field.

A different updating method that attempted to take secular acceleration into account was investigated; however, the particular method tried resulted in larger estimated errors. Research to determine the best method for predicting the geomagnetic field is continuing but has not been completed.

The secular variation model NOARL80S was based on secular variation models produced at NOARL based on annual mean data from 73 magnetic observatories that had continuous vector data from 1961.5 through 1983.5. No observatory data later than 1983.5 were used for any of the models. There are some large regions of the Earth where there were no observatories that had continuous vector data for the chosen time period.

More recent observatory measurements are now available and have been supplied to NOARL by NAVOCEANO on magnetic tape. An improved geomagnetic field model could be produced for epoch 1990.5 and model accuracy estimated by using much the same approach that was used for the production of NOARL90, but using more recent

observatory data and a larger number of observatories better distributed about the Earth. It is possible to select a larger number of observatories by removing the requirement that the observatories have continuous vector data back to 1961.5. The requirement that the data be continuous back to 1961.5 relates to the NOARL research program; however, this requirement is not necessary or desirable for the specific goal of producing an epoch 1990.5 magnetic field model.

6. References

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TABLE 1. NOARL90 EPOCH 1990.5 PREDICTIVE FIELD MODEL

N	M	G(N,M)	H(N,M)
1	0	-29755.9	0.0
1	1	-1836.5	5428.9
2	0	-2166.4	0.0
2	1	3058.1	-2265.0
2	2	1720.9	-434.8
3	0	1298.8	0.0
3	1	-2240.2	-298.1
3	2	1230.6	299.7
3	3	825.9	-326.9
4	0	931.5	0.0
4	1	773.4	253.5
4	2	328.1	-245.9
4	3	-431.6	87.5
4	4	141.9	-303.2
5	0	-214.5	0.0
5	1	354.6	54.7
5	2	248.7	148.3
5	3	-110.0	-160.8
5	4	-168.8	-73.1
5	5	-45.1	96.7
6	0	54.9	0.0
6	1	67.9	-17.5
6	2	61.8	86.8
6	3	-178.7	66.2
6	4	12.3	-46.3
6	5	15.1	2.5
6	6	-106.4	23.5
7	0	78.9	0.0
7	1	-64.0	-84.4
7	2	3.7	-26.4
7	3	24.2	2.5
7	4	-1.5	21.8
7	5	5.9	18.0
7	6	8.1	-19.9
7	7	-2.5	-8.3
8	0	21.0	0.0
8	1	5.3	6.4
8	2	0.1	-21.6
8	3	-11.4	5.3
8	4	-10.4	-23.8
8	5	4.6	11.2
8	6	5.8	11.9
8	7	4.0	-16.7
8	8	-2.7	-15.3

TABLE 1. (CONTINUED)

N	M	G(N,M)	H(N,M)
9	0	5.4	0.0
9	1	8.5	-20.7
9	2	1.0	16.4
9	3	-11.6	10.5
9	4	8.5	-6.5
9	5	-4.4	-7.5
9	6	-1.2	6.6
9	7	8.2	8.6
9	8	3.3	-6.5
9	9	-6.1	2.0
10	0	-4.0	0.0
10	1	-4.0	1.0
10	2	2.0	0.0
10	3	-5.0	3.0
10	4	-2.0	6.0
10	5	5.0	-4.0
10	6	3.0	0.0
10	7	1.0	-1.0
10	8	2.0	4.0
10	9	3.0	0.0
10	10	0.0	-6.0

TABLE 2. DGRF80 EPOCH 1980.5 STANDARD FIELD MODEL

N	M	G(N,M)	H(N,M)
1	0	-29992.	0.
1	1	-1956.	5604.
2	0	-1997.	0.
2	1	3027.	-2129.
2	2	1663.	-200.
3	0	1281.	0.
3	1	-2180.	-336.
3	2	1251.	271.
3	3	833.	-252.
4	0	938.	0.
4	1	782.	212.
4	2	398.	-257.
4	3	-419.	53.
4	4	199.	-297.
5	0	-218.	0.
5	1	357.	46.
5	2	261.	150.
5	3	-74.	-151.
5	4	-162.	-78.
5	5	-48.	92.
6	0	48.	0.
6	1	66.	-15.
6	2	42.	93.
6	3	-192.	71.
6	4	4.	-43.
6	5	14.	-2.
6	6	-108.	17.
7	0	72.	0.
7	1	-59.	-82.
7	2	2.	-27.
7	3	21.	-5.
7	4	-12.	16.
7	5	1.	18.
7	6	11.	-23.
7	7	-2.	-10.
8	0	18.	0.
8	1	6.	7.
8	2	0.	-18.
8	3	-11.	4.
8	4	-7.	-22.
8	5	4.	9.
8	6	3.	16.
8	7	6.	-13.
8	8	-1.	-15.

TABLE 2. (CONTINUED)

N	M	G(N,M)	H(N,M)
9	0	5.	0.
9	1	10.	-21.
9	2	1.	16.
9	3	-12.	9.
9	4	9.	-5.
9	5	-3.	-6.
9	6	-1.	9.
9	7	7.	10.
9	8	2.	-6.
9	9	-5.	2.
10	0	-4.	0.
10	1	-4.	1.
10	2	2.	0.
10	3	-5.	3.
10	4	-2.	6.
10	5	5.	-4.
10	6	3.	0.
10	7	1.	-1.
10	8	2.	4.
10	9	3.	0.
10	10	0.	-6.

TABLE 3. NOARL80S EPOCH 1980.0 SECULAR VARIATION MODEL

N	M	G(N,M)	H(N,M)
1	0	23.608	0.000
1	1	11.954	-17.508
2	0	-16.939	0.000
2	1	3.113	-13.599
2	2	5.787	-23.475
3	0	1.776	0.000
3	1	-6.019	3.791
3	2	-2.037	2.874
3	3	-0.709	-7.492
4	0	-0.653	0.000
4	1	-0.860	4.153
4	2	-6.992	1.111
4	3	-1.256	3.452
4	4	-5.709	-0.616
5	0	0.350	0.000
5	1	-0.241	0.868
5	2	-1.231	-0.168
5	3	-3.595	-0.977
5	4	-0.681	0.490
5	5	0.292	0.474
6	0	0.688	0.000
6	1	0.189	-0.245
6	2	1.978	-0.624
6	3	1.330	-0.483
6	4	0.825	-0.325
6	5	0.111	0.454
6	6	0.157	0.651
7	0	0.690	0.000
7	1	-0.500	-0.237
7	2	0.173	0.057
7	3	0.320	0.749
7	4	1.048	0.578
7	5	0.492	0.004
7	6	-0.286	0.312
7	7	-0.055	0.172
8	0	0.298	0.000
8	1	-0.067	-0.059
8	2	0.005	-0.356
8	3	-0.043	0.133
8	4	-0.339	-0.179
8	5	0.056	0.221
8	6	0.282	-0.415
8	7	-0.201	-0.371
8	8	-0.174	-0.033

TABLE 3. (CONTINUED)

N	M	G(N,M)	H(N,M)
9	0	0.045	0.000
9	1	-0.148	0.032
9	2	0.002	0.036
9	3	0.045	0.147
9	4	-0.049	-0.152
9	5	-0.138	-0.148
9	6	-0.020	-0.245
9	7	0.120	-0.141
9	8	0.128	-0.053
9	9	-0.107	-0.002

TABLE 4. ESTIMATED RMS MEASUREMENT ERRORS AND MODEL ERRORS AT 73 MAGNETIC OBSERVATORIES

Units are nT/yr . Letters X, Y, and Z refer to north, east, and vertical field components, respectively. Field components are in geomagnetic coordinates.

OBSERVATORY	GEOGRAPHIC LAT	GEOGRAPHIC LONG	MEAS. ERROR X	MEAS. ERROR Y	MEAS. ERROR Z	MODEL ERROR X	MODEL ERROR Y	MODEL ERROR Z	PERCENT MODEL ERROR X	PERCENT MODEL ERROR Y	PERCENT MODEL ERROR Z
ALIBAG	18.638	72.872	15.8	5.2	19.7	5.0	4.1	7.8	31.6	78.2	39.6
ALMERIA	36.853	-2.460	4.1	2.2	5.4	1.8	1.4	2.3	44.6	63.5	42.1
APIA	-13.807	-171.775	2.7	2.9	4.5	2.6	2.9	4.4	96.7	97.5	98.0
ARGENTINE ISLAND	-65.245	-64.258	3.5	2.8	2.9	3.3	2.8	2.8	94.8	98.1	99.3
BAKER LAKE	64.333	-96.033	12.6	29.7	14.6	2.2	2.1	3.3	17.3	6.9	22.9
BANGUI	4.437	18.565	4.6	9.4	7.4	3.8	6.1	6.4	82.0	65.6	86.2
BEIJING	40.040	116.175	4.1	1.8	6.0	1.6	1.4	2.4	40.0	77.4	40.3
CAPE WELLEN	66.163	-169.835	8.8	13.4	8.9	2.9	2.4	2.5	33.5	17.8	28.7
CHA PA	22.350	103.833	15.0	9.7	24.8	4.7	3.8	5.9	31.4	39.4	23.6
CHAMBON-LA-FORET	48.023	2.260	2.3	2.4	3.2	0.6	0.6	0.7	24.8	24.1	21.8
COLLEGE	64.860	-147.837	3.2	1.2	2.6	2.0	1.1	2.0	63.9	91.0	75.3
DIXON ISLAND	73.543	80.562	15.6	5.4	16.7	3.0	2.9	4.1	19.3	53.7	24.3
DOMBAS	62.073	9.117	2.1	2.1	1.8	0.7	0.5	0.8	32.9	23.8	41.9
DOURBES	50.097	4.595	1.1	1.7	2.3	0.4	0.5	0.6	36.9	27.1	24.5
DUSHETI	42.092	44.705	1.5	1.5	2.2	1.3	1.4	1.8	91.0	90.7	83.2
ESKDALEMUIR	55.317	-3.200	1.6	1.2	6.3	0.5	0.5	0.7	33.9	41.7	11.5
FREDERICKSBURG	38.205	-77.373	2.2	1.2	2.6	1.9	1.2	2.5	86.7	96.2	95.8
FURSTENFELDBRUCK	48.165	11.277	2.2	1.1	1.0	0.4	0.4	0.5	18.1	38.4	54.3
GNANGARA	-31.783	115.950	2.0	1.5	2.2	2.0	1.5	2.2	97.9	98.8	99.4
GODHAVN	69.252	-53.533	2.6	1.6	6.7	1.9	1.3	3.7	73.1	83.7	55.2
GORNOTAYEZHNAYA	43.683	132.167	2.5	2.9	11.9	1.1	1.1	1.8	46.4	38.1	14.7
GROCKA	44.633	20.767	1.3	1.0	2.4	0.6	0.5	0.9	44.0	51.2	35.9
GUAM	13.583	144.870	5.7	1.8	3.3	3.4	1.7	2.9	60.1	93.3	88.5
HARTLAND	50.995	-4.483	1.7	2.1	1.5	0.6	0.6	0.8	35.1	28.3	53.3
HEL	54.608	18.815	2.5	2.7	2.6	0.4	0.4	0.6	16.3	14.9	24.1
HERMANUS	-34.425	19.225	1.2	1.0	4.0	1.2	1.0	3.7	98.8	99 3	91.9
HONOLULU	21.320	-158.002	2.7	1.4	2.4	2.6	1.4	2.3	94.3	99.1	99.2
HUANCAYO	-12.045	-75.340	2.6	2.5	3.1	2.4	2.4	3.0	92.1	96.9	97.3
HURBANOVO	47.873	18.190	2.6	1.8	3.0	0.4	0.4	0.6	16.6	22.9	20.3
KAKIOKA	36.230	140.190	0.4	0.6	0.8	0.4	0.5	0.6	92.7	86.5	70.0
KANOYA	31.420	130.882	1.9	1.3	0.9	1.0	0.9	0.8	52.2	69.6	87.0
KANOZAN	35.253	139.960	1.4	1.6	0.9	0.4	0.5	0.6	28.5	32.0	64.4
L AQUILA	42.383	13.317	1.6	1.8	1.5	0.8	0.7	0.9	49.2	40.7	57.1
LEIRVOGUR	64.183	-21.700	4.1	1.7	2.7	1.5	1.1	1.7	36.2	66.1	62.5
LERWICK	60.133	-1.183	1.2	1.8	1.5	0.7	0.6	0.8	61.1	30.7	55.1
LOVO	59.345	17.827	1.2	0.6	1.0	0.5	0.4	0.6	46.8	74.8	64.5
LVOV	49.900	23.750	6.0	2.1	7.2	0.5	0.5	0.8	8.2	24.0	10.6

TABLE 4. (CONTINUED)

OBSERVATORY	GEOGRAPHIC LAT	GEOGRAPHIC LONG	MEAS. ERROR X	MEAS. ERROR Y	MEAS. ERROR Z	MODEL ERROR X	MODEL ERROR Y	MODEL ERROR Z	PERCENT MODEL ERROR X	PERCENT MODEL ERROR Y	PERCENT MODEL ERROR Z
M BOUR	14.392	-16.958	3.5	3.4	3.3	3.2	3.1	3.1	91.3	91.5	95.5
MACQUARIE ISLAND	-54.500	158.950	3.3	8.0	7.4	3.1	6.8	7.0	95.4	84.5	95.0
MAPUTO	-25.917	32.583	6.1	3.2	8.0	4.1	2.9	5.3	68.0	90.5	67.1
MAWSON	-67.605	62.882	6.6	4.2	13.6	4.5	3.5	8.0	67.6	84.3	59.3
MEANOOK	54.617	-113.333	6.5	3.4	3.8	1.8	1.6	2.2	27.9	45.9	57.5
MEMAMBETSU	43.907	144.193	2.0	1.1	2.9	1.3	0.9	1.4	62.3	81.1	48.6
MIRNY	-66.550	93.017	8.4	11.3	19.3	4.6	4.7	8.3	54.7	42.1	42.8
MUNTINLUPA	14.375	121.015	6.8	7.7	12.3	4.1	3.7	5.1	59.6	47.5	41.3
NAGYCENK	47.633	16.717	8.7	5.5	7.0	0.4	0.4	0.6	4.9	7.5	8.5
NIEMEGK	52.072	12.675	0.4	1.0	3.1	0.3	0.4	0.5	76.2	34.3	17.0
NURMIJARVI	60.508	24.655	9.7	3.6	6.9	0.7	0.6	0.8	7.1	17.2	11.3
PANAGYURISHTE	42.515	24.177	1.2	1.4	3.3	0.8	0.6	1.1	69.3	45.3	34.2
PATRONY	52.167	104.450	2.0	3.6	3.9	1.8	2.6	3.3	86.3	70.6	83.5
PILAR	-31.667	-63.883	10.9	3.1	4.3	5.0	2.8	4.0	45.6	88.9	93.0
PLESHENITZI	54.500	27.883	3.9	7.4	4.0	0.6	0.7	0.9	14.2	9.5	22.8
PORT MORESBY	-9.408	147.152	6.1	1.5	8.3	4.5	1.4	7.0	73.3	98.0	84.8
PORT-AUX-FRANCAIS	-49.350	70.200	5.5	4.6	1.7	4.6	3.8	1.6	83.6	83.1	99.0
RESOLUTE BAY	74.700	-94.900	2.5	4.7	7.5	1.7	2.4	4.4	70.0	50.5	59.3
SAN JUAN	18.113	-66.150	2.4	1.8	3.0	2.2	1.7	2.8	91.1	97.0	94.1
SHESHAN	31.097	121.187	2.3	2.6	4.7	1.6	1.4	1.8	66.8	55.9	37.8
SITKA	57.058	-135.325	2.7	0.9	3.0	1.7	0.8	1.7	62.9	89.1	56.7
SODANKYLA	67.368	26.630	2.4	1.2	2.0	1.3	0.9	1.2	53.1	80.3	60.7
STEPANOVKA	46.783	30.883	2.4	1.8	3.4	0.7	0.8	1.1	28.4	41.8	31.1
SURLARI	44.680	26.253	12.3	3.8	20.0	0.7	0.6	1.0	5.5	16.4	5.1
TAMANRASSET	22.792	5.527	7.5	20.5	16.5	3.3	2.7	4.8	44.3	13.1	28.9
TIHANY	46.900	17.893	6.1	4.3	20.0	0.5	0.4	0.6	7.6	10.0	3.2
TRIVANDRUM	8.483	76.950	6.7	10.7	8.8	5.6	5.8	7.5	83.1	53.8	85.3
TUCSON	32.247	-110.833	4.1	3.1	4.7	3.6	2.6	3.8	86.9	85.1	81.7
VALENTIA	51.933	-10.250	1.4	0.9	1.9	0.8	0.8	1.0	55.0	81.9	52.3
VASSOURAS	-22.400	-43.650	12.4	7.0	5.0	6.8	5.2	4.6	55.1	74.9	91.2
VICTORIA	48.517	-123.417	2.6	1.6	2.6	1.8	1.3	1.9	70.5	81.9	72.9
VOYEYKOVO	59.950	30.705	3.9	3.0	3.9	0.8	0.9	1.0	20.1	29.5	25.4
WIEN-KOBENZL	48.265	16.318	1.0	1.4	1.4	0.4	0.4	0.6	42.4	29.3	41.5
WINGST	53.743	9.073	1.5	0.9	1.8	0.3	0.4	0.5	23.2	38.5	29.3
WITTEVEEN	52.813	6.668	6.0	1.7	1.3	0.4	0.4	0.5	5.9	22.7	42.5
YUZHNO SAKHALIN	46.950	142.717	6.0	9.6	3.4	1.6	1.2	1.8	27.2	12.3	52.1

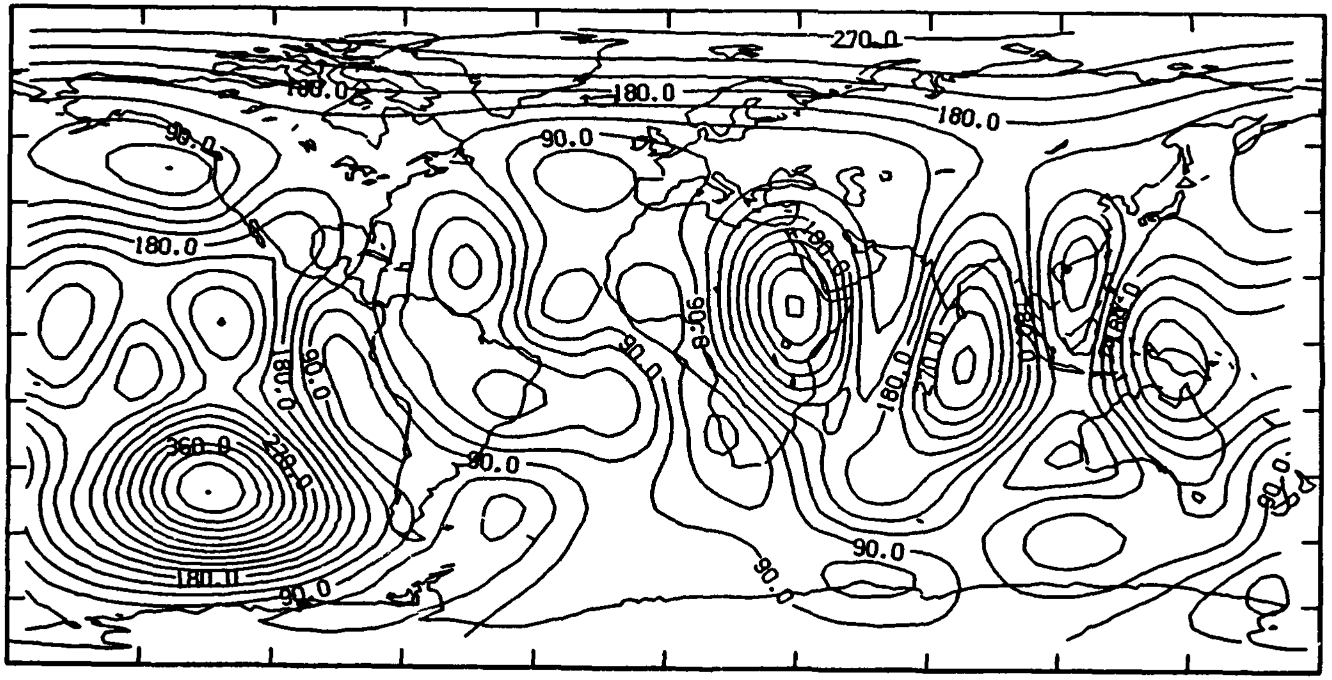

FIGURE 1. MAGNITUDE OF DIFFERENCE FIELD FOR PREDICTIVE FIELD MODELS. NOARL90 - GSFC90. Units are nT.

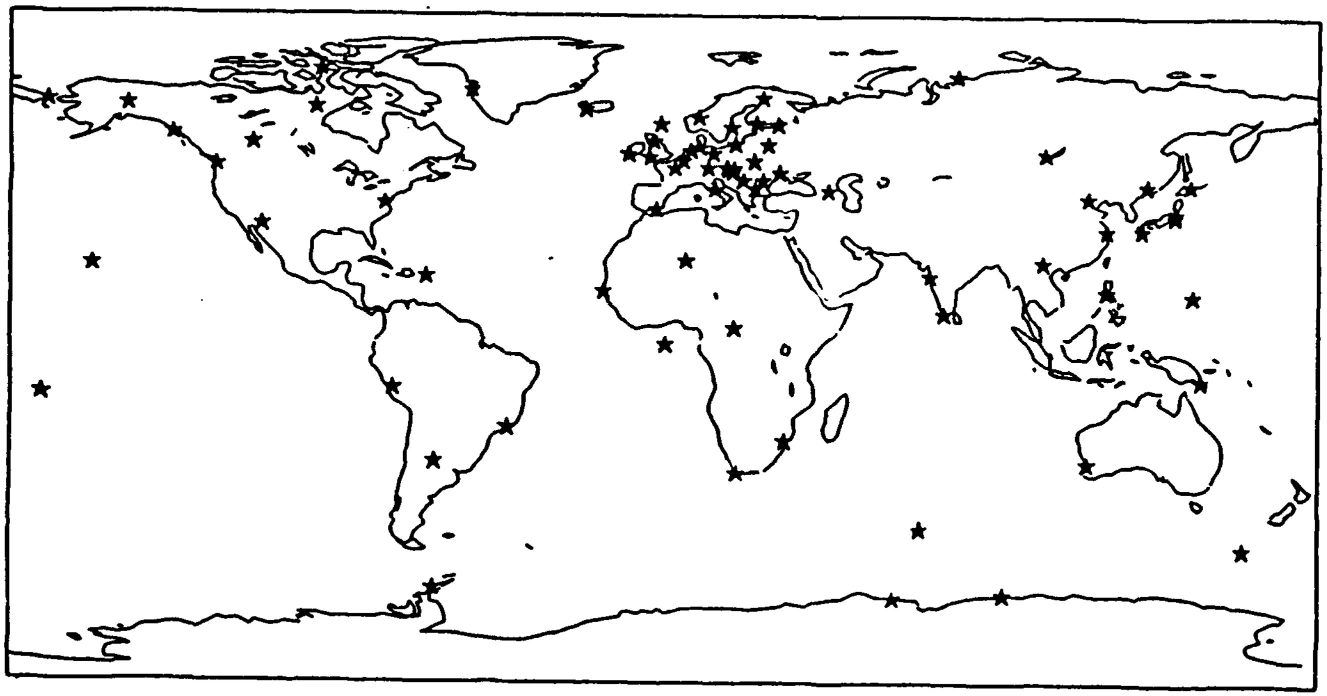

FIGURE 2(a). LOCATIONS OF MAGNETIC OBSERVATORIES USED FOR NOARL80S SECULAR VARIATION MODEL.

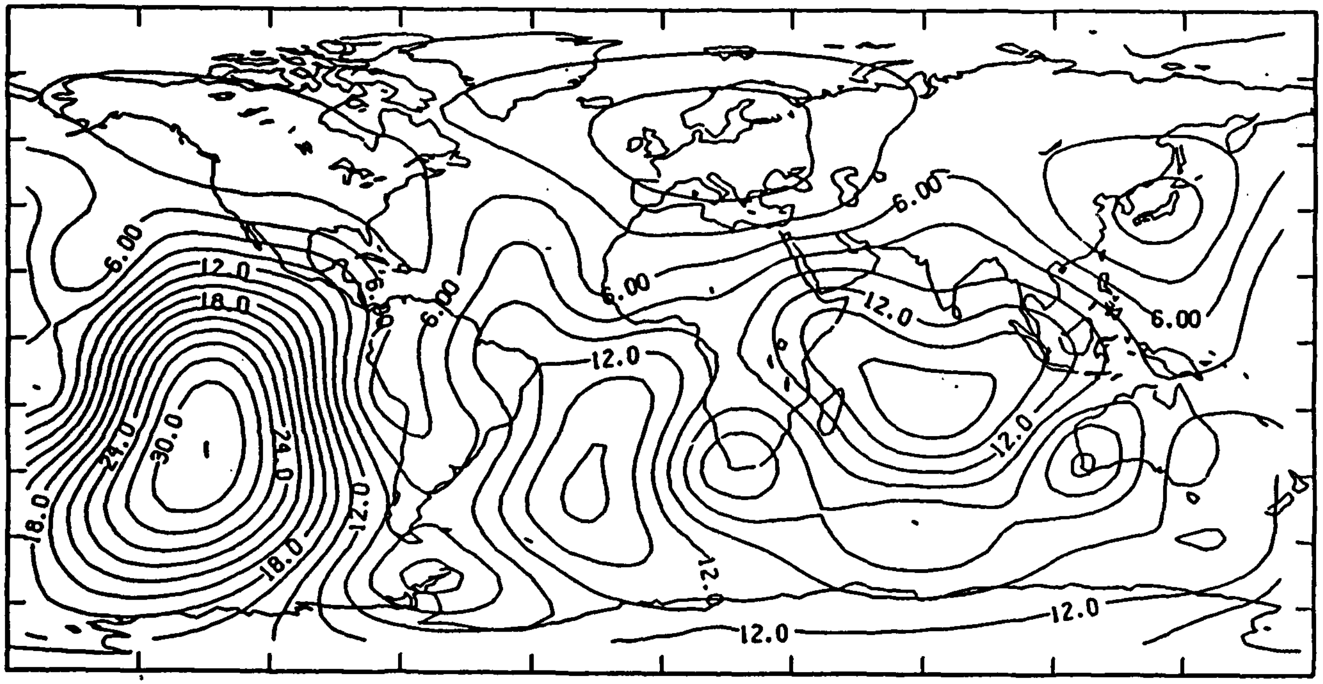

FIGURE 2(b). ESTIMATED MAGNITUDE OF VECTOR FIELD ERROR FOR NOARL SECULAR VARIATION MODELS. Seven of these secular variation models were averaged to produce NOARL80S. Units are nT/yr.

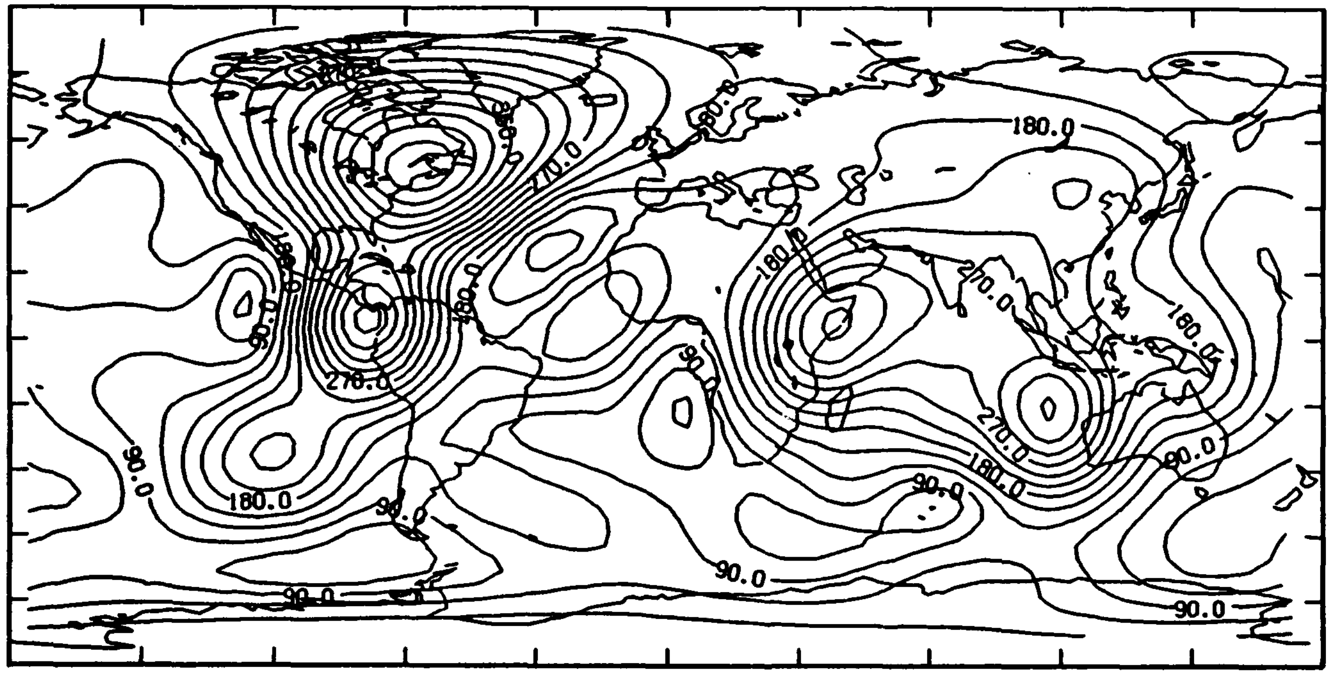

FIGURE 3(a). MAGNITUDE OF DIFFERENCE FIELD FOR PREDICTIVE FIELD MODEL NOARL80 MINUS STANDARD MODEL DGRF80. Units are nT.

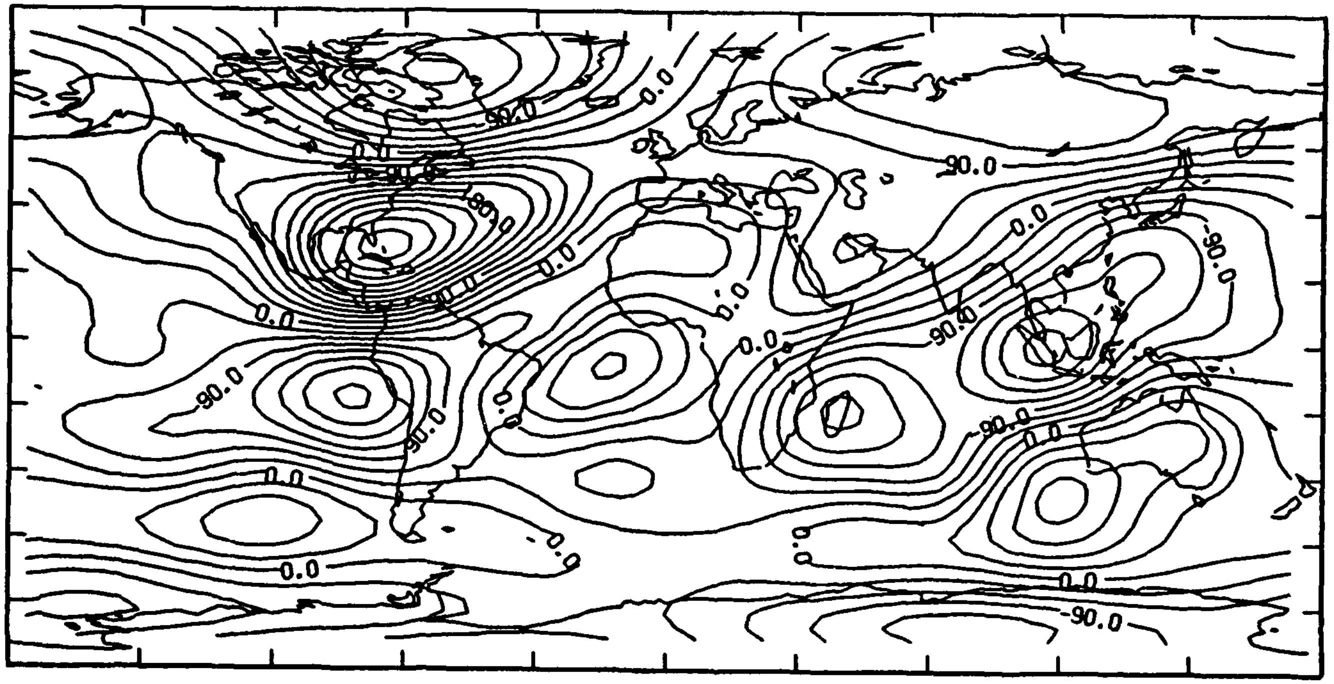

FIGURE 3(b). NORTH COMPONENT OF DIFFERENCE FIELD FOR PREDICTIVE FIELD MODEL NOARL80 MINUS STANDARD MODEL DGRF80. Units are nT.

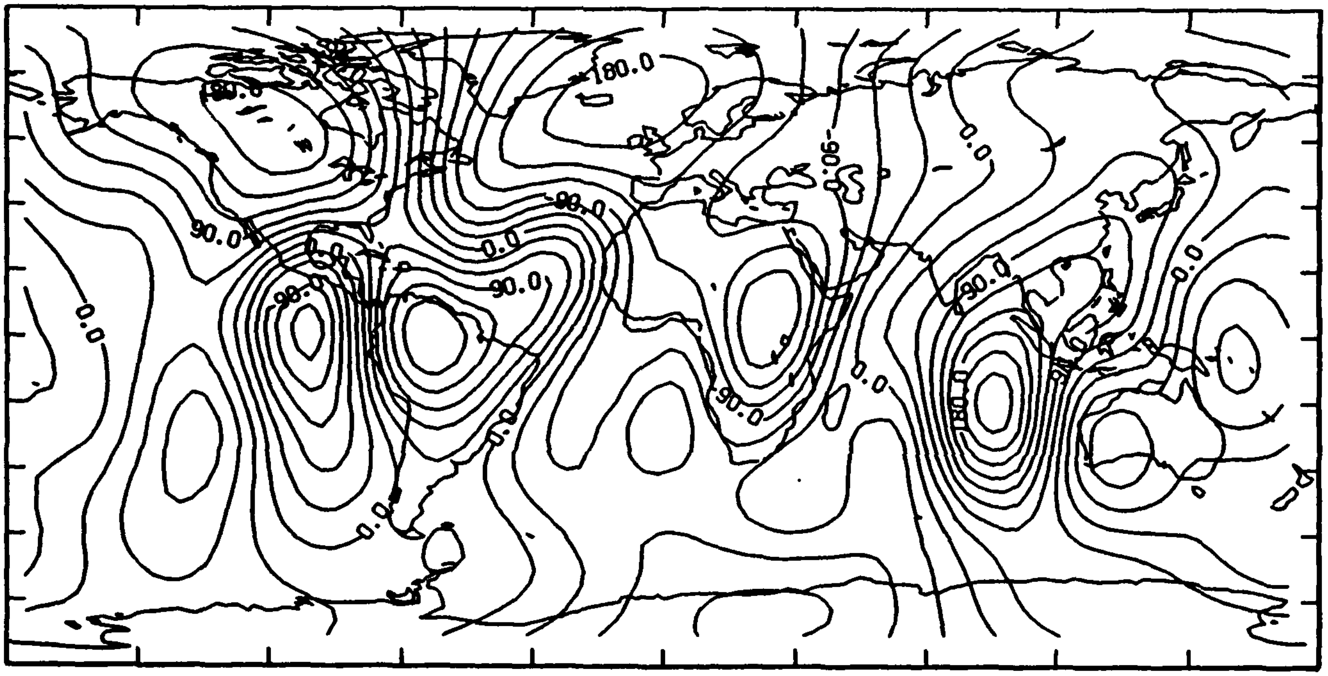

FIGURE 3(c). EAST COMPONENT OF DIFFERENCE FIELD FOR PREDICTIVE FIELD MODEL NOARL80 MINUS STANDARD MODEL DGRF80. Units are nT.

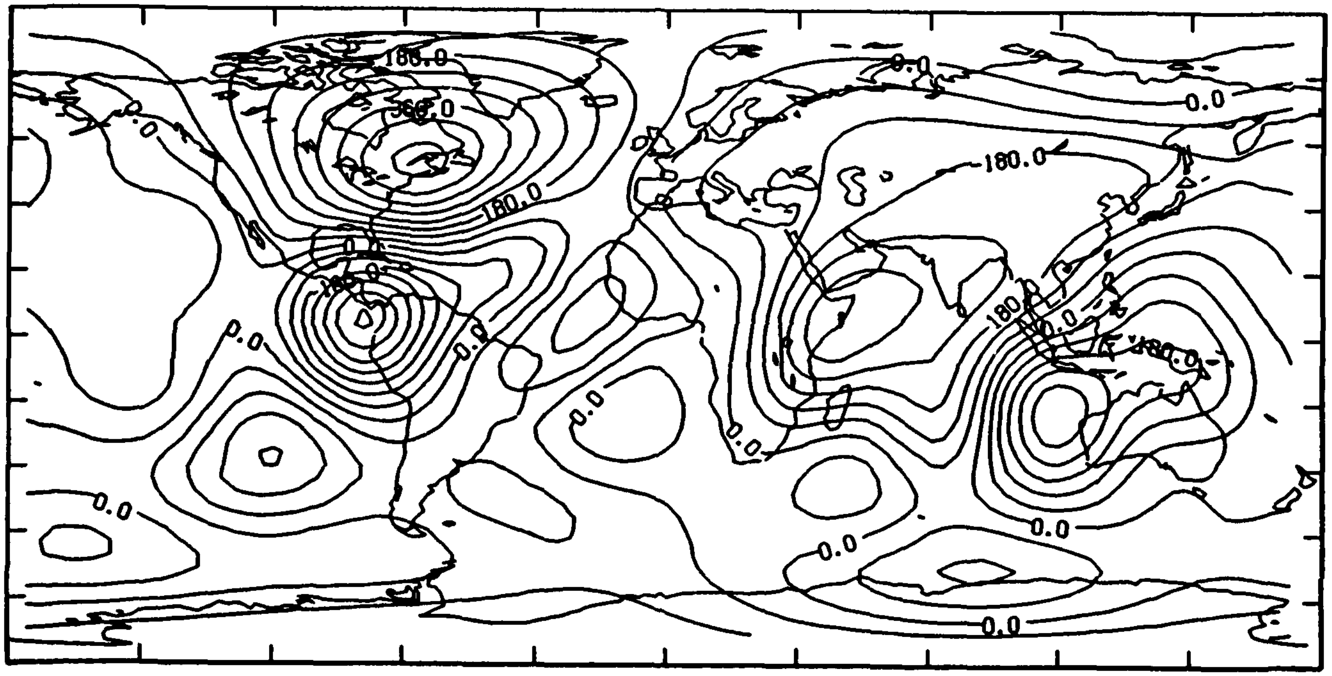

FIGURE 3(d). VERTICAL COMPONENT OF DIFFERENCE FIELD FOR PREDICTIVE FIELD MODEL NOARL80 MINUS STANDARD MODEL DGRF80. Units are nT.

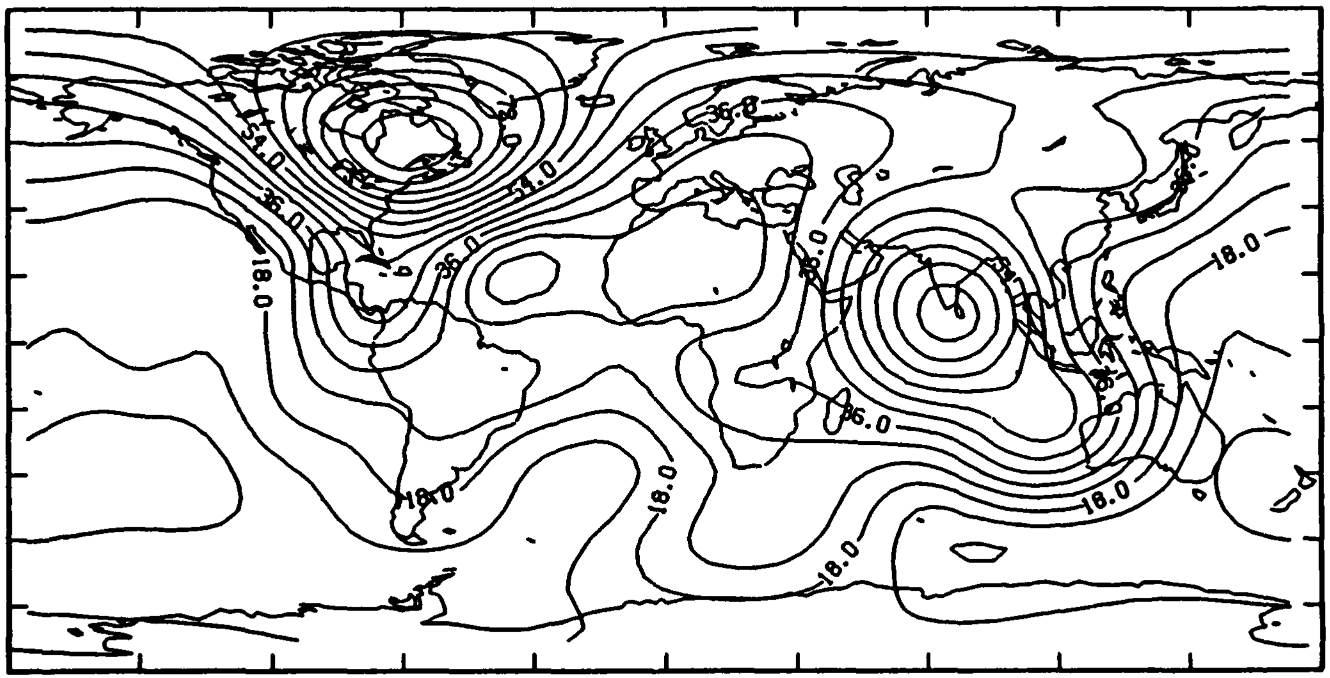

FIGURE 4(a). MAGNITUDE OF DIFFERENCE FIELD FOR SECULAR VARIATION MODEL NOARL80S MINUS SECULAR VARIATION MODEL NOARL70S. Units are nT/yr.

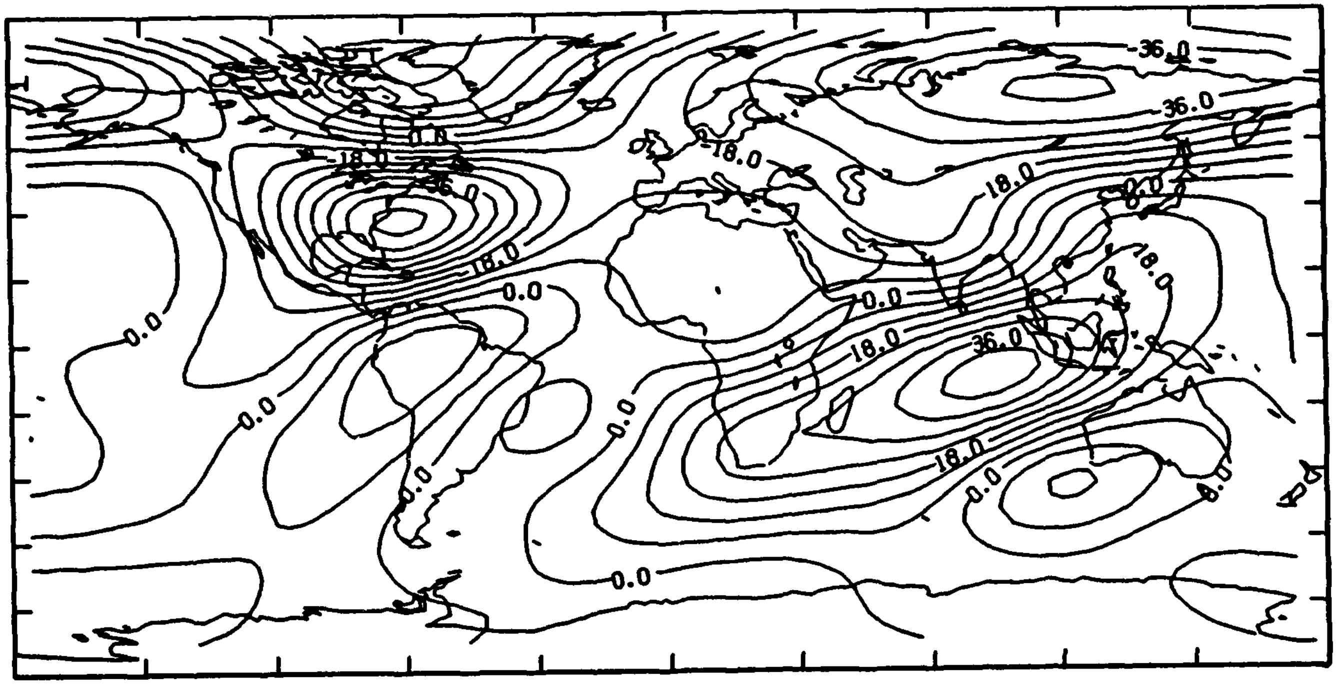

FIGURE 4(b). NORTH COMPONENT OF DIFFERENCE FIELD FOR SECULAR VARIATION MODEL NOARL80S MINUS SECULAR VARIATION MODEL NOARL70S. Units are nT/yr.

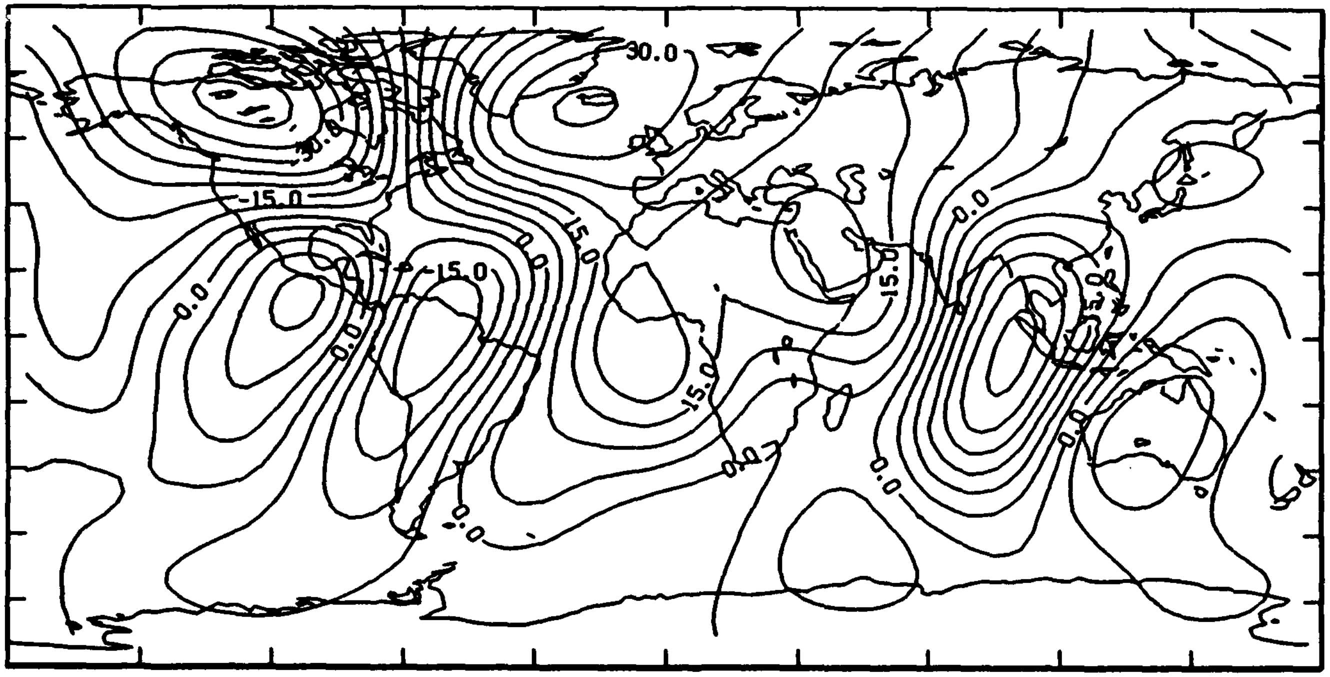

FIGURE 4(c). EAST COMPONENT OF DIFFERENCE FIELD FOR SECULAR VARIATION MODEL NOARL80S MINUS SECULAR VARIATION MODEL NOARL70S. Units are nT/yr.

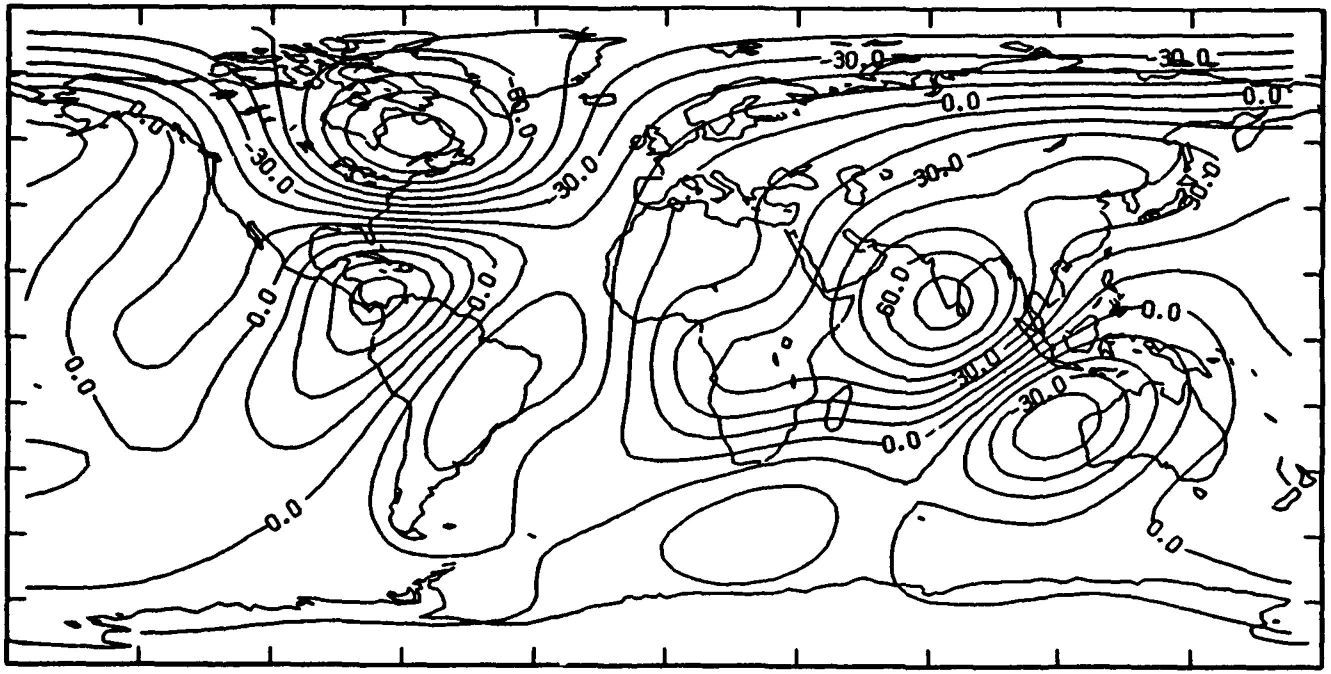

FIGURE 4(d). VERTICAL COMPONENT OF DIFFERENCE FIELD FOR SECULAR VARIATION MODEL NOARL80S MINUS SECULAR VARIATION MODEL NOARL70S. Units are nT/yr.

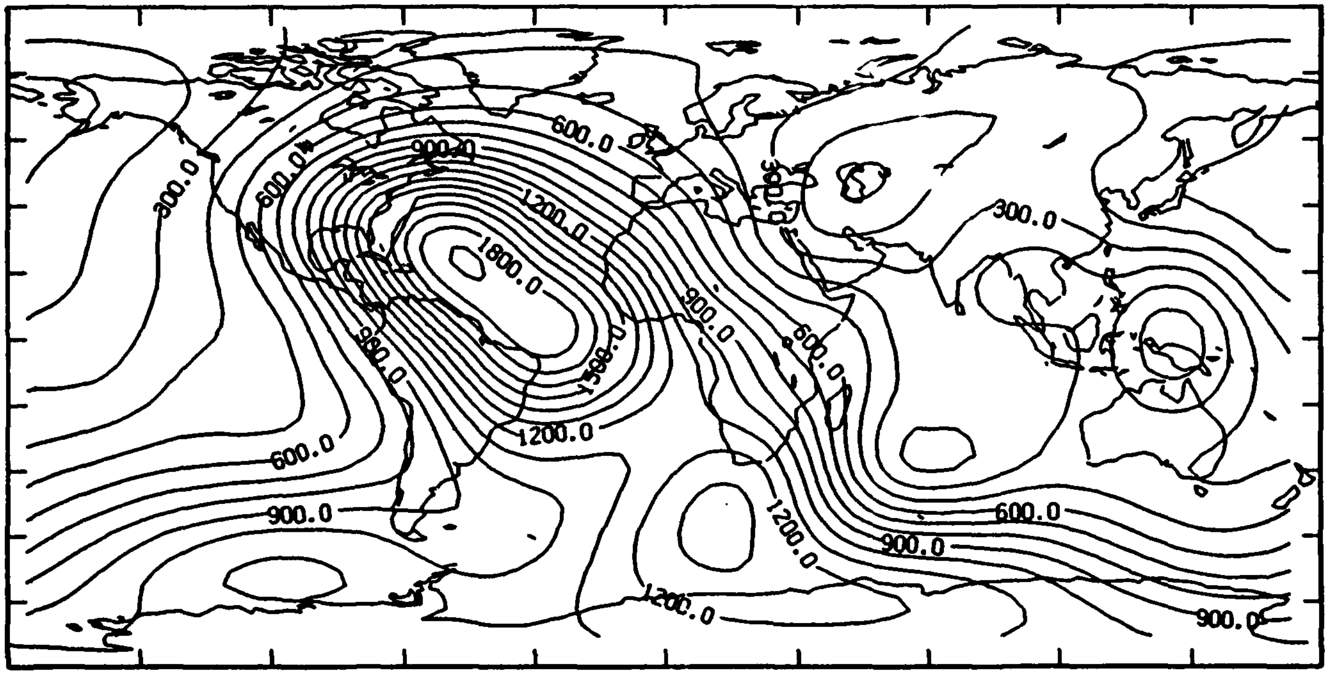

FIGURE 5. CHANGE OF GEOMAGNETIC FIELD 1970-1980. Magnitude of difference field for model DGRF80 minus model DGRF70. Units are nT.

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A predictive model of the geomagnetic field for epoch 1990.5 has been developed. The model is based on the DGRF model for 1980.5 updated to 1990.5 by use of a secular variation model for 1980.0 developed at the Naval Oceanographic and Atmospheric Research Laboratory (NOARL). The NOARL secular variation model is based upon annual means of vector geomagnetic field components from 73 magnetic observatories for years 1976. 5 through 1983.5. The predictive model is of degree and order 10.

The rms error of the predictive model is estimated to be 200 nT relative to an accurate degree 10 field model for epoch 1990.5. Peak errors relative to an accurate model are estimated to be 500 nT for vector field error magnitude and ±350, ±250, and ±500 nT for north, east, and vertical field components errors, respectively. If the DGRF model for 1980.5 were used without updating to represent the degree 10 field for 1990.5, estimated errors would be about four times as large.

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